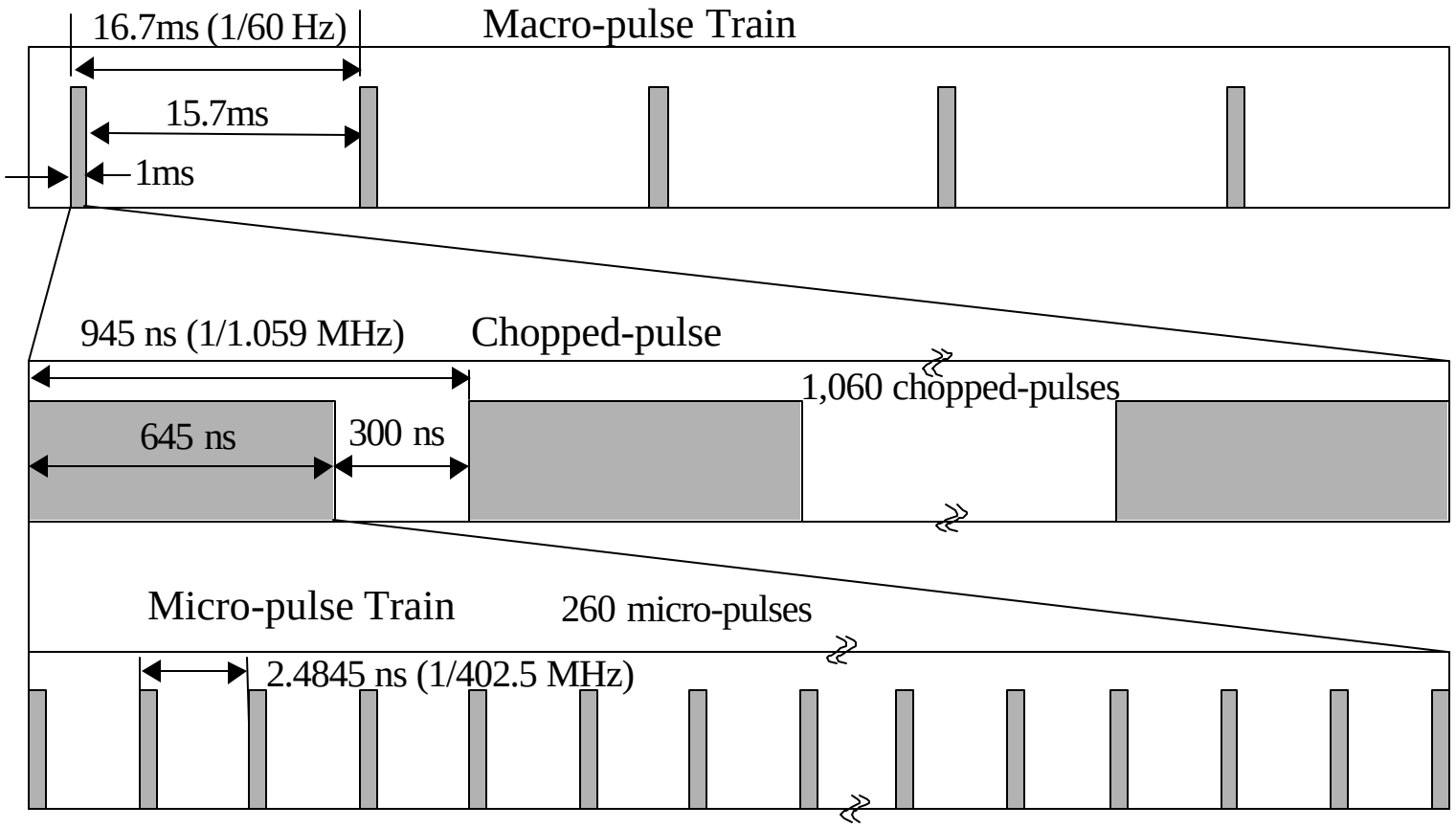
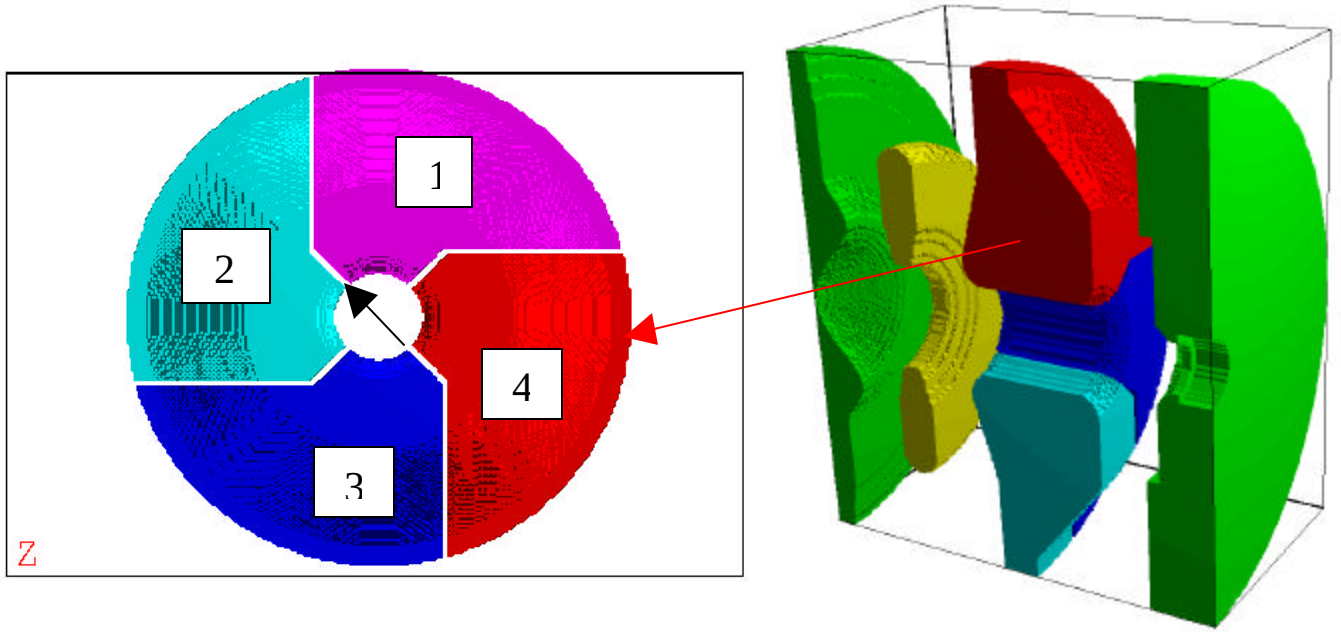
Time Structure

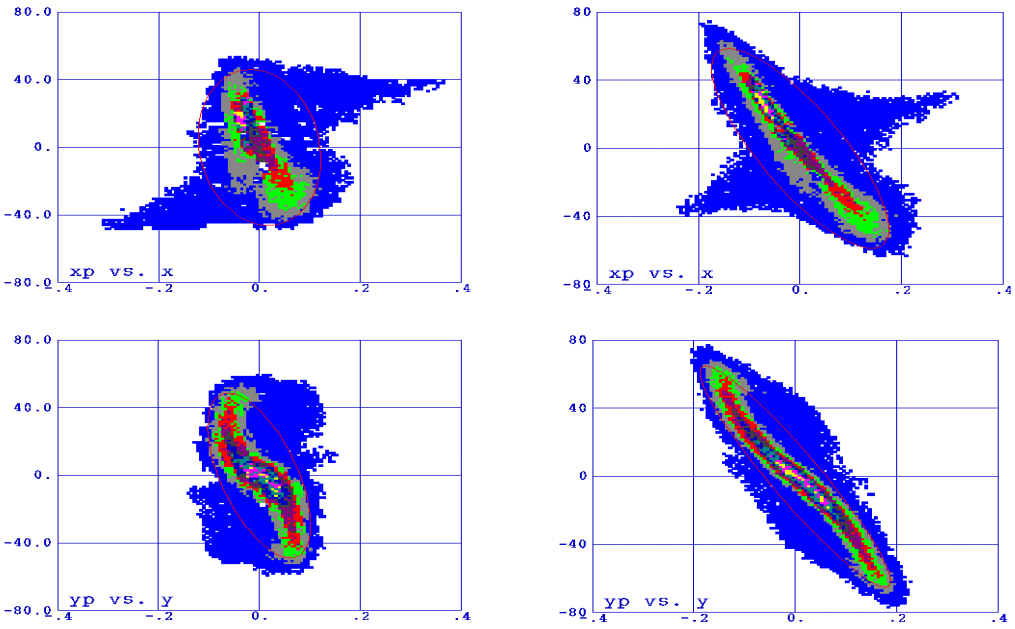


LEBT Chopper Structure



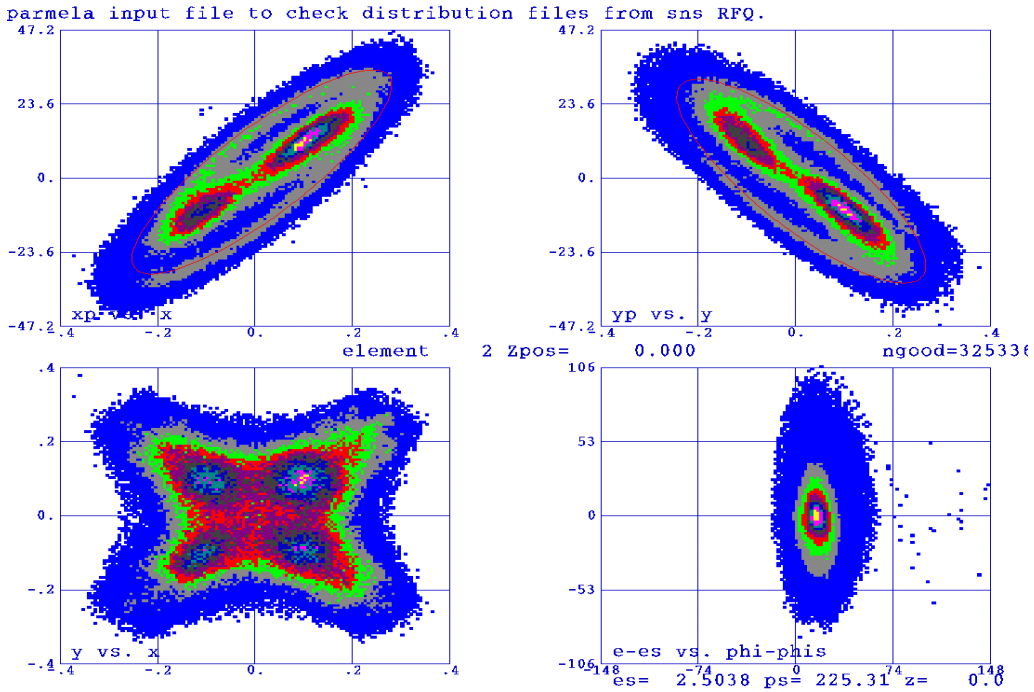
- Collectively electrodes operate at -40 kV
- ± 2 kV superimposed on opposing segments
- Beams deflected at 45, 135, 225, 315 degrees
- During a 300 ns chopping gap, the electrodes maintain a constant orientation
- Chopped beam from successive gaps are sequentially deflected in 4 quadrants
- For rise (fall) time 25 ns, up to 20 pulses in each gap may be partially deflected

Particle Beam Reconstruction from Measurement



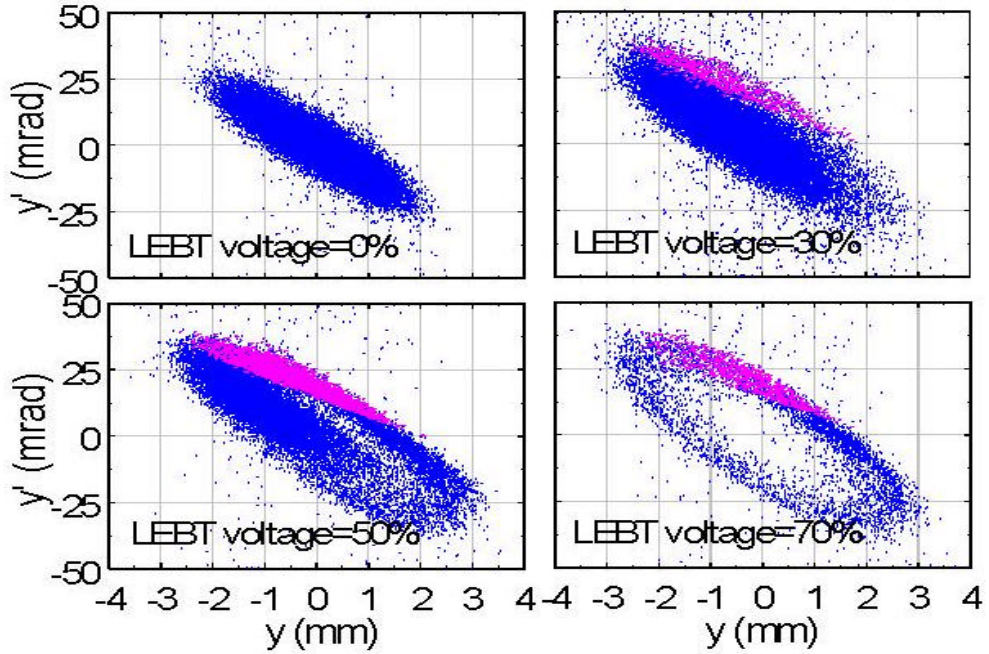
- Initial particle distribution derived from x and y beam emit measurements made at slightly different z locations
- This particle distribution continues backwards through the LEBT to a reference point well before the electrodes
- Code PARMELA used with 3-D space charge and axial field map for backward transport with LEBT chopper fields turned off
- Complete reversibility for forward and reverse transport ensured

Four Partially chopped Beam at the RFQ exit



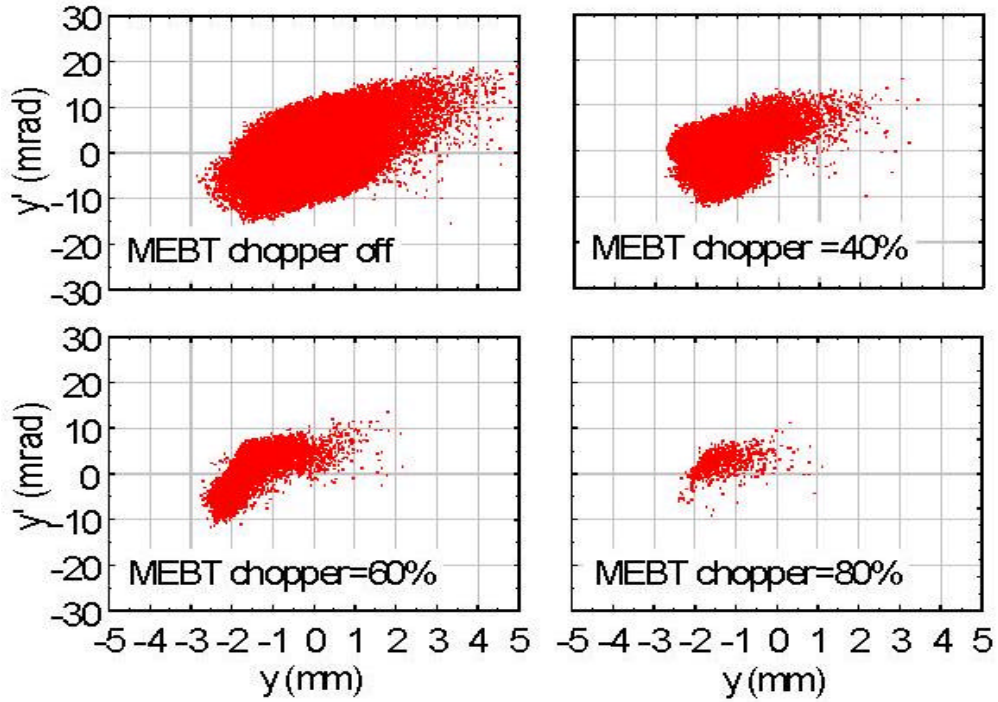
- With LEBT off, beam enters the RFQ matched
- Beam enters the RFQ off-axis and off-angle with LEBT partially on
- Superposition of beams in 4 quadrants with LEBT chopper @ 1 kV (relative) i.e., 50% of max.
- Represents beam transmitted through the MEBT during LEBT transients

Evolution During LEBT Voltage Ramp



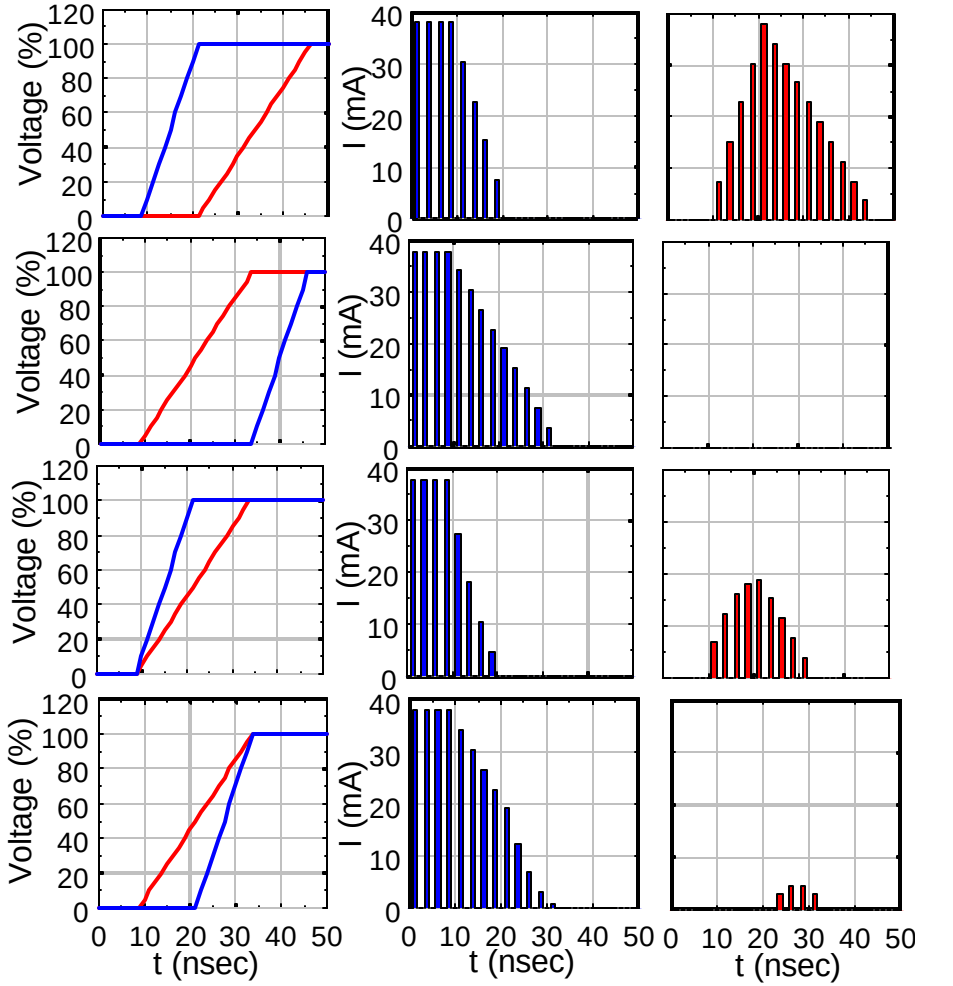
- Follow beam deflected at 1st quadrant by LEBT during ramp
- Blue dots : survive through the RFQ; Big emittance increase during ramp
- Red dots : co-ordinates of particles at the RFQ exit that survive thru the MEBT

Y- Y’ @ DTL-Input with MEBT Chopper Acting Alone



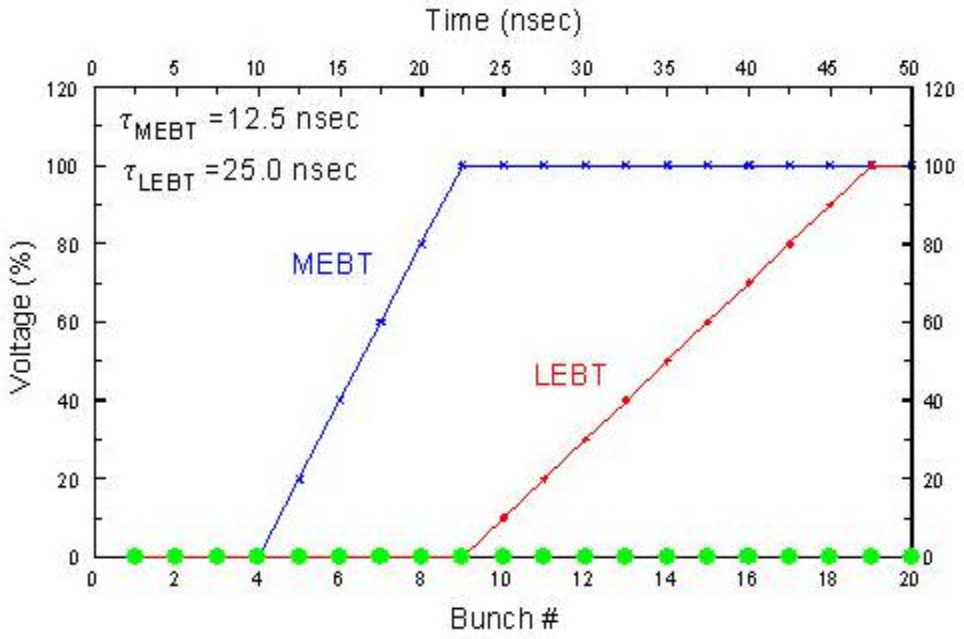
- The asymmetry of the unchopped beam reflects the missing 1% removed by the chopper target
- During transient beam nominally remains within the phase space defined by the matched beam
- With full MEBT voltage, 17 μA (peak) enters the linac -- gap cleanliness ratio of 1: 5 x 10^{-4} not enough to meet the gap-current goal

The Chopper Timing Options



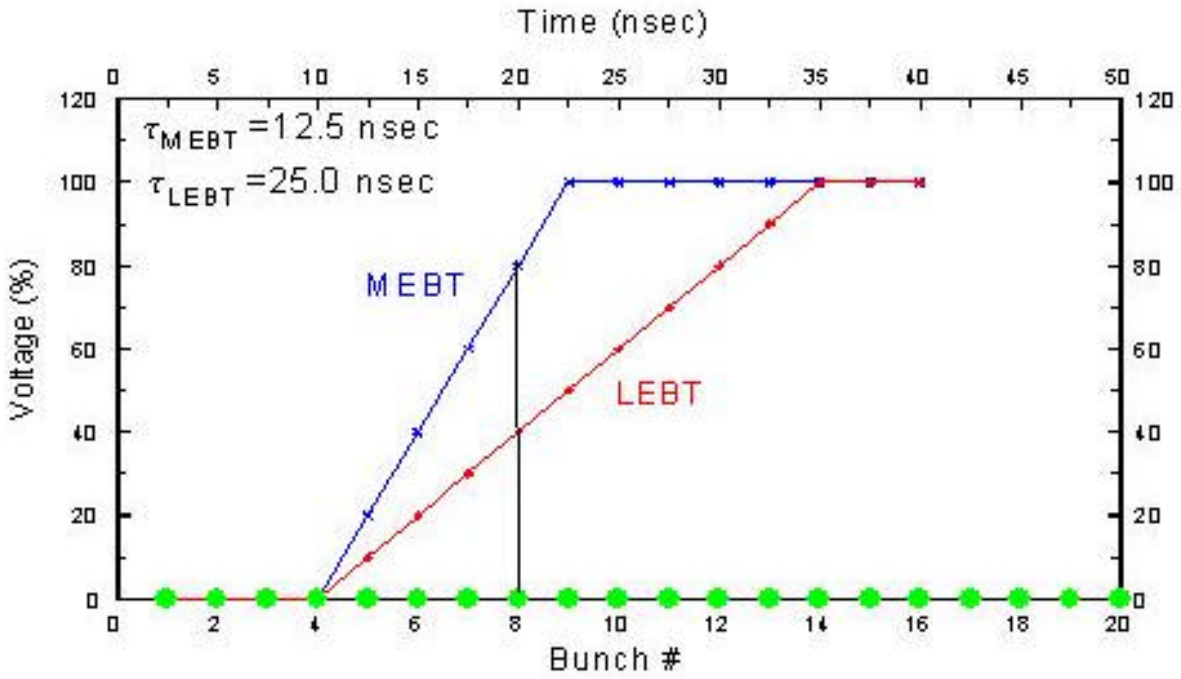
- In Option 1, MEBT chopper turns on first
  - minimizes stray beam entering the linac
  - results in maximum power dissipation in the chopper target
- In Option 2, LEBT chopper turns on first
  - no beam in the chopper target
  - maximizes beam loss in the linac during ramp
- In option 3 and 4, starts and ends at the same time respectively.

Detailed Timing Pattern for Option 1



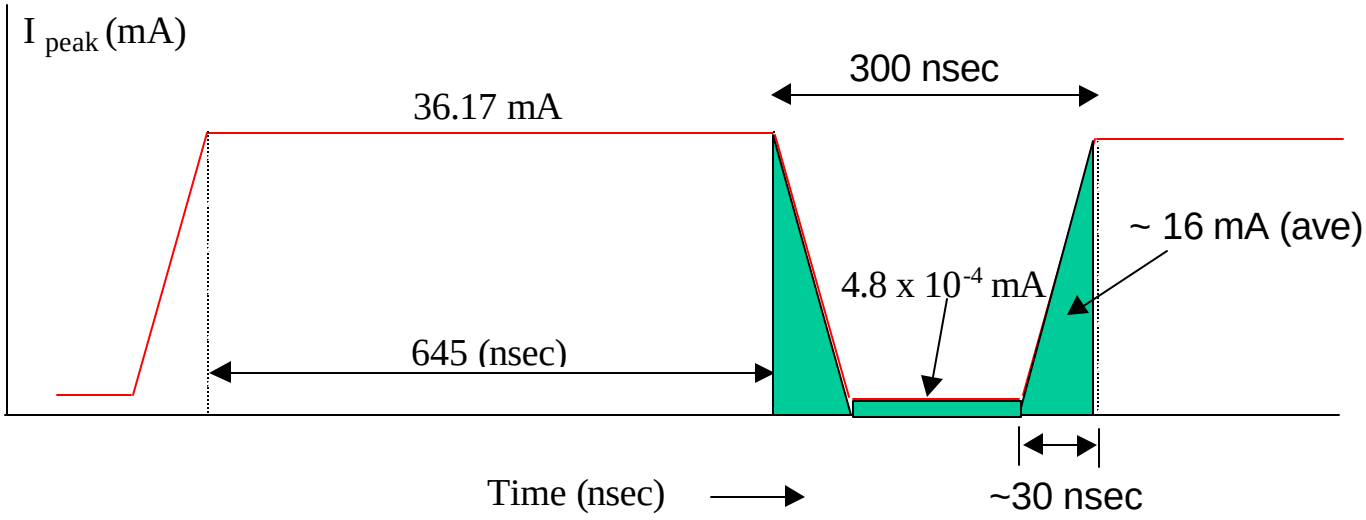
- Assumed LEBT and MEBT rise (fall) time are conservative - actual values are smaller
  - **provides upper bound for power estimates**
- MEBT starts first; LEBT starts when MEBT attains full voltage i.e., all LEBT partially chopped pulses see full MEBT voltage

Detailed Timing Pattern for Option 3



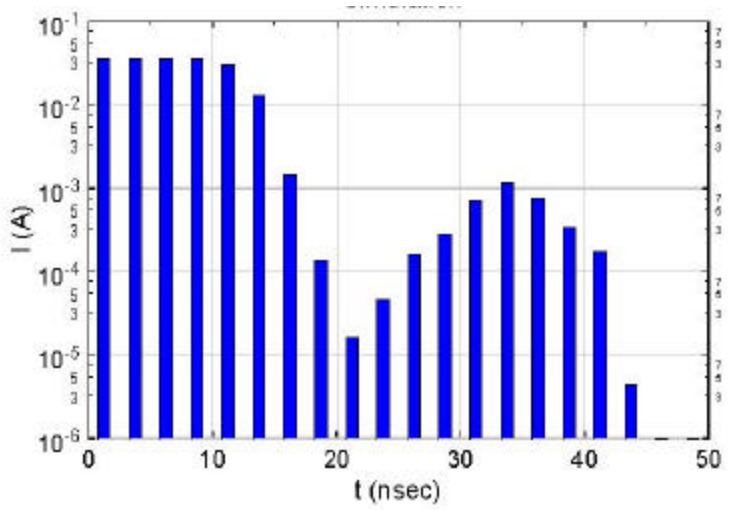
- MEBT and LEBT starts at the same time
- Four LEBT partially chopped bunches, 5, 6, 7 and 8 th, also see partial MEBT voltage
- All bunches starting with 9th see full MEBT voltage

Beam-current entering DTL

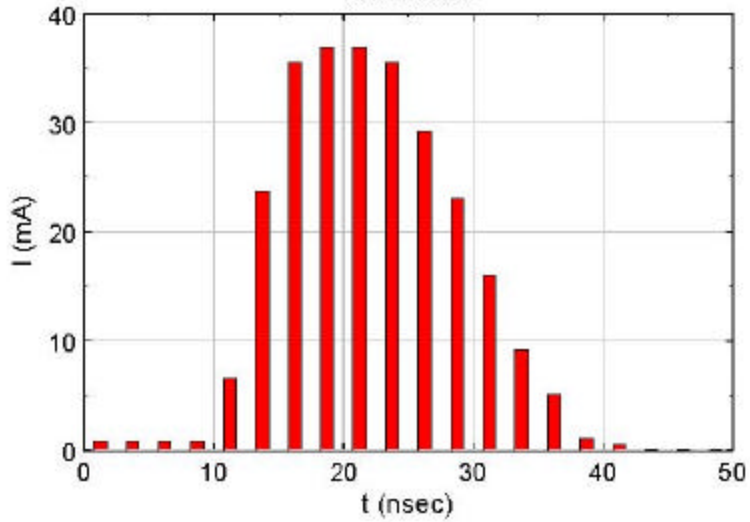


- Chopper-gap cleanliness : ~ 1.3 X 10^{-5}
- About 1% (16 A ave out of 1.55 mA ave) is contained in the transient
  - obviously **can't afford to loose all in the linac**

Simulated Beam Current vs. Time for Option 1



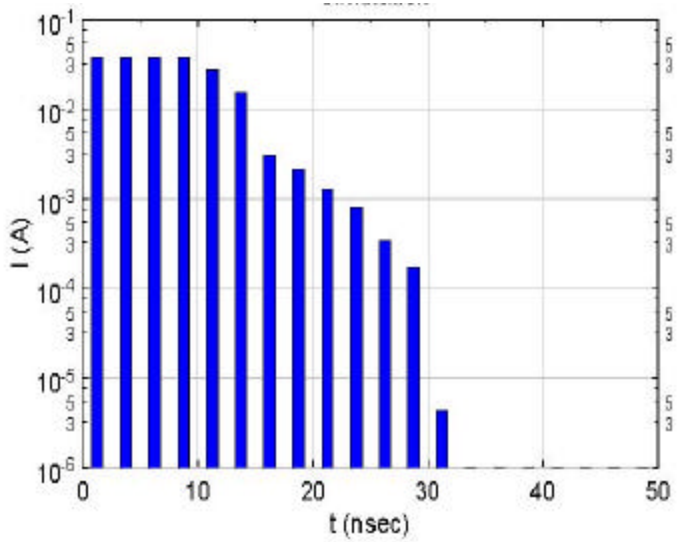
@ DTL Input



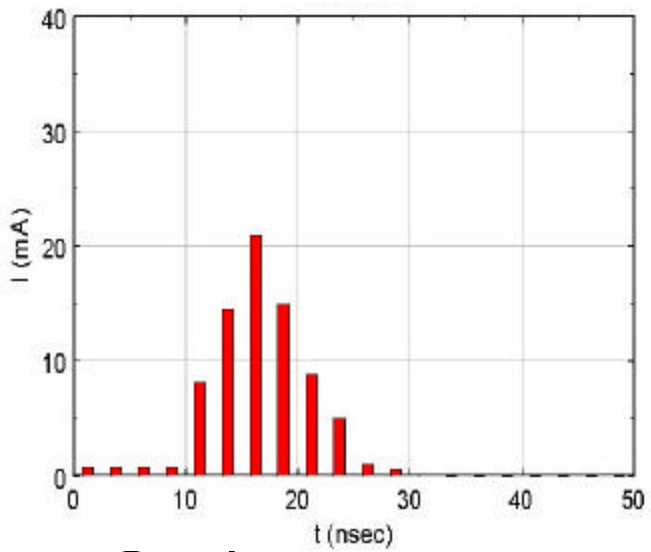
@ Chopper Target

- DTL input beam decreases by 3 orders of magnitude but increases again briefly (by 2 orders) during LEBT transient
- Beam transient lasts for ~ 30 nsec
- Average current entering DTL ~ 15.6 A
- Ave power dissipation at target: 205 W (in addition to 39 W intercepted all the time)

Simulated Beam Current vs. Time for Option 3



@ DTL Input



@ Chopper Target

- DTL input beam decreases exponentially during transient
- Transient duration ~ 20 nsec
- Average current entering DTL ~ 16.2 A
- Average power dissipation at target: 58 W (in addition to 39 W intercepted all the time)

Linear Model Predictions and Simulation

chopper timing option	average linac current during transient	average MEBT target power dissipation
	(μA)	(W)
1	24	226
2	54	0
3	19	87
4	49	12
1, Simulation	15.6	205
3, Simulation	16.2	58.5

- Options 1 and 3 reduce the current in the linac
- MEBT turned on first (Option 1 and 3): maximizes gap length, minimizes potential for losing partially chopped bunches
- LEBT turned on first (Option 2 and 4): reduces the beam current entering MEBT target but spoils emittance; increased potential for beam loss in the linac

Option 1 vs. Option 3

- Reduces the current in the linac
- Transient length: ~ 30 nsec
- Average current entering the linac : ~ 15.6 A
- Average power dissipation in the target: 205 W

- Reduces the current in the linac
- Transient length ~ 20 nsec
- Average current entering the linac : ~ 16.2 A
- Average power dissipation in the target: 58 W

Summary

- Only option 1 and 3 was confirmed by particle simulation
- Both options meet gap cleanliness requirement of 1: 10^{-4}
- Option 3 appears to be most attractive
  - it minimizes the potential for beam loss in the linac
  - easily meets the chopper target power limitations
- For both of the above options, average beam entering the DTL is ~ 16 A.
  - Beam entering the linac remains nominally within the phase space defined by the matched beam